



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

**In re application of:** Jiao et al.

**Application No.** 10/522,850

**Filed:** January 28, 2005

**Confirmation No.** 1884

**For:** METHOD FOR SYNTHESIZING  
NANOSCALE STRUCTURES IN  
DEFINED LOCATIONS

**Examiner:** Daniel H. Miller

**Art Unit:** 1775

**Attorney Reference No.** 3005-66286-03

CERTIFICATE OF MAILING

I hereby certify that this paper and the documents referred to as being attached or enclosed herewith are being deposited with the United States Postal Service as First Class Mail in an envelope addressed to: COMMISSIONER FOR PATENTS, P.O. BOX 1450, ALEXANDRIA, VA 22313-1450 on the date shown below.

Attorney or Agent  
for Applicant(s)

Date Mailed July, 2006

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**DECLARATION UNDER 37 C.F.R. § 1.131**

I, Professor Jun Jiao, hereby declare as follows:

1. I am an inventor named on the application referenced above. I currently am a professor of Physics at Portland State University, and have been working in the field of nanoscience and nanotechnology for 13+ years. My resume is attached hereto as Exhibit A.
2. I have read the Office Action dated April 27, 2006, concerning the application referenced above. I understand that claims 1-4, 6-8, and 17-19 are rejected as allegedly being taught by Schlaf *et al.*'s U.S. Patent No. 6,871,528. I also understand that claims 20 and 21 are rejected as allegedly being obvious over Li *et al.*'s U.S. Patent No. 6,831,017 when combined with Dai *et al.*'s U.S. Patent No. 6,346,189.
3. Attached hereto as Exhibit B are true and accurate photocopies of notebook pages from co-inventor Sean Foxley. Mr. Foxley worked in my laboratories at Portland State University to develop embodiments of inventions disclosed in the referenced application. Dates stated on these notebook pages have been redacted, but were made contemporaneously with the work done as summarized by the text stated on such pages. I hereby declare that all dates stated by Mr. Foxley's original notebook and attached as Exhibit B are prior to April 5, 2002.

4. Claim 1 of the referenced application first requires a substrate. Page 13 of Mr. Foxley's notebook states "a PoSi substrate" was used for this particular embodiment.

5. Claim 1 then requires that a pillar be formed on the substrate. An entry on page 13 of Mr. Foxley's notebook states that a platinum tower was formed by deposition. The specific features associated with the deposition, including the current and the size of the pillar array formed, also are disclosed.

6. Claim 1 requires that the pillar further comprises a catalyst. The platinum pillar produced by deposition was then "sputter coated w/Co target for 90 sec at 32 mA current." This statement, adjacent numbered paragraph 3 on page 13 of Exhibit B, establishes that a catalyst was sputter coated on top of platinum pillars.

7. Claim 1 requires forming a nanoscale structure on the pillar. As discussed on page 3 of the corresponding PCT application as published, lines 23-24, nanotubes are one example of a nanoscale structure. Page 14 of attached Exhibit B, adjacent numbered paragraph 4, states that the substrate having pillars formed thereon was "put in reaction chamber - cross referenced to reaction chamber log to find parameters ...." The substrate having platinum pillars and catalysts thereon was put into the reaction chamber to form carbon nanotubes on top of the pillar by chemical deposition. Documents from the inventors' reaction chamber log also are attached hereto as Exhibit C. Exhibit C states the conditions used to form carbon nanotubes on the platinum pillars.

8. Attached hereto as Exhibit D are images made contemporaneously, or substantially contemporaneously, with the work done as stated on Exhibit B. Moreover, all images attached hereto as Exhibit D were produced well prior to April 5, 2002. These images establish both formation of pillars, as well as carbon nanotubes on top of such pillars. Thus, the invention of claim 1 was conceived, and reduced to practice, prior to April 5, 2002.

9. Certain of the claims, such as claim 5, state that the pillar is electrically connected to an electronic device. One purpose for depositing pillars, and thereafter forming nanostructures on the pillar, is to produce electronic devices. For example, page 4 of the published PCT application, lines 14-16, list examples of specific electronic components. A conducting or semi-conducting substrate material is used, such as polysilicon, such that any pillar formed thereon can be electrically connected to an electronic device. Thus, the attached Exhibits establish an invention date of claim 5 prior to April 5, 2002.

10. Claim 6 requires that the catalyst be deposited on the pillar. The platinum pillar produced by deposition was then "sputter coated w/Co target for 90 sec at 32 mA current." This statement, adjacent numbered paragraph 3 on page 13 of Exhibit B, establishes that a catalyst was sputter coated on top of platinum pillars.

11. Claim 8 concerns carbon nanotubes. Carbon nanotubes formed on pillars are depicted in the attached images of Exhibit D.

12. Claim 9 concerns the structure of a field emitter device comprising a pillar on a tungsten tip, along with a nanotube formed on the tip. Page 5 of Exhibit B states that the "tungsten tip had tubes. There was a pretty high yield of small diameter tubes on the tip." Thus, the structure recited in claim 9, i.e. a tungsten tip with a nanotube or nanotubes grown thereon, is clearly established by page 5 of Exhibit B.

13. Claim 12 refers to transistors. A transistor can be formed comprising a structure whereby two pillars are interconnected by a horizontally grown nanotube structure, such as a carbon nanotube. In such structures, the substrate acts as the gate. See page 4 of the application, lines 16-22. The images of Exhibit D show platinum pillars interconnected with carbon nanotubes, both horizontally grown and vertically grown. Such structures can act as transistors, and hence the attached documents establish conception and reduction to practice of the invention recited in claim 12 well prior to April 5, 2002.

14. Claims 13-16 refer to the size of the carbon nanotubes. Each of the images attached hereto includes a scale bar, typically ranging from 2 microns to 5 microns, to establish the size of structures depicted by such images. The features recited in claims 13-16 with reference to the size of the nanoscale structure, such as nanotubes, are determined by reference to the scale bars provided with such images.

15. Claims 17 and 18 refer to substrates. Exhibit B teaches using silicon as a substrate, and hence establishes conception and reduction to practice of the invention recited in claims 17 and 18.

16. Certain other claims, such as claim 19, refer to nanoscale structures formed out of specific materials, such as carbon. Conception and reduction to practice of such claims is established by the attached documents and images depicting carbon nanotubes.

17. Certain of the claims, such as claim 22, require forming plural pillars, and plural nanoscale structures formed on the pillars. The images attached hereto as Exhibit D clearly

demonstrate formation of plural pillars, such as plural platinum pillars, having plural nanoscale structures formed thereon, such as plural carbon nanotubes.

18. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Jun Jiao  
Professor Jun Jiao, Inventor

July 12, 2006  
Date

## CURRICULUM VITAE

**Jun Jiao**

January 30, 2006

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### EDUCATION

Ph.D.            1997    Materials Science and Engineering, University of Arizona, Tucson, AZ  
M.S.            1993    Physics, University of Arizona, Tucson, AZ  
B.S.            1982    Optical Sciences, Shandong University, Jinan, Shandong, China

### EMPLOYMENT EXPERIENCE

#### **Portland State University, Portland, Oregon 1999 – Present**

**Director,**            Center for Electron Microscopy and Nanofabrication (February 2003 – present)  
**Professor**           Department of Physics (June 2006 –Present)  
**Professor**           Department of and Electrical and Computer Engineering (June 2006-Present). This  
                                 is joint appointment  
**Associate professor,** Department of Physics (June 2004 – June 2006)  
**Assistant professor,** Department of Physics (September 16, 1999 – May 2004)

#### **University of Arizona, Tucson, Arizona 1991 – August, 1999**

**Assistant Research Scientist,** Department of Materials Science and Engineering (May 1997 – August 1999)  
**Graduate Research Associate,** Department of Materials Science and Engineering (1995 – May 1997)  
**Graduate Research Assistant,** Department of Materials Science and Engineering (1993 – 1994)  
**Graduate Teaching Assistant,** Department of Physics (1991 - 1992)

#### **Shandong University, Jinan, P.R. China 1982 – 1990**

**Lecturer (Faculty Status),** Department of Optical Sciences (1982 - 1990)

### Dissertation

**Title:** "Comparative Study of the Properties, Morphologies, and Structures of Carbon Nanoclusters  
Prepared by Different Methods."  
**Institution:** Department of Materials Science and Engineering, University of Arizona  
**Dissertation director:** Prof. Supapan Seraphin  
**Finishing date:** May 30, 1997

### Refereed Publications and Other Creative Achievements

#### ***Refereed Journal Papers:***

1. **J. Jiao, L.F. Dong, V. Chirayos, J. Bush, J. Hedberg,** "Methods for Dispersion and Alignment of Single-Walled Carbon Nanotubes and Effects on Their Structural and Electronic Properties," to be published in *International Journal of Nanoscience* (2006).



2. J.M. Green, L.F. Dong, T. Gutu, **J. Jiao**, J.F. Conley, Jr. and Y. Ono, "ZnO-Nanoparticle-Coated Carbon Nanotubes Demonstrating Enhanced Electron Field-Emission Properties," *J. Appl. Phys.*, Vol. 99, 094308-4 (2006).
3. D. McClain, R. Solanki, L.F. Dong, **J. Jiao** "Synthesis of Single Crystalline Silicon Nanowires and Investigation of Their Electron Field Emission," *J. Vac. Sci. Technol. B*, Vol. 24 (1), 20-24, January (2006).
4. L.F. Dong, J. Bush, V. Chirayos, R. Solanki, **J. Jiao**, Y. Ono, J. F. Conley, Jr., B. D. Ulrich, "Dielectrophoretic Controlled Fabrication of Single Crystal Nickel Silicide Nanowire Interconnects and the Investigation of Their Formation Mechanism," *Nano Letters*, Vol. 5 No. 10 2112-2115 (2005).
5. L.F. Dong, V. Chirayos, J. Bush, **J. Jiao**, V.M. Dubin, R.V. Chebian, Y. Ono, J.F. Conley, Jr., and B.D. Ulrich, "Floating-Potential Dielectrophoresis Controlled Fabrication of Single Carbon Nanotube Transistors and Their Electrical Properties," *J. Phys. Chem. B*. Vol. 109, No. 27, 131148-13153 (2005).
6. L.F. Dong and **J. Jiao**, "Electron Microscopy Study of Exotic Nanostructures of Cadmium Sulfide," *Microscopy and Microanalysis*, Vol. 11. No. 2, 116-123 (2005).
7. J. Hedberg, L.F. Dong, and **J. Jiao**, "Air Flow Technique for Large Scale Dispersion and Alignment of Carbon Nanotubes on Various Substrates," *Appl. Phys. Lett.*, Vol. 86, No. 14, 144311-144313 (2005).
8. F.Q. Tang, X.W. Meng, **J. Jiao**, "Using Silver Nanoparticle to Enhance Current Response of Biosensor," *Surf. Interface Anal.*, Vol. 36, 489-492 (2005).
9. G.L. Rorrer, C.H. Chang, S.H. Liu, C. Jeffries, **J. Jiao**, and J. Hedberg, "Biosynthesis of Silicon-Germanium Oxide Nanocomposites by the Marine Diatom *Nitzschia Frustulum*," *J. Nanosci. Nanotech.*, Vol. 5. 41-49 (2005).
10. L.F. Dong, T. Gushtyuk, **J. Jiao**, "Synthesis, Characterization and Growth Mechanism of Self-assembled Dendritic CdS Nanorods," *J. Phys. Chem. B*, Vol. 108, 1617-1620 (2004).
11. E. Einarsson, D.W. Tuggle, and **J. Jiao**, "In Situ Alignment of Carbon Nanocoils and Their Field Emission Behavior Induced by an Electric Field," *Appl. Phys. A*. Vol. 79, 2049-2054 (2004).
12. D.W. Tuggle. **J. Jiao** and L.F. Dong, "Field Emission Current Fluctuations from Isolated Carbon Nanotubes," *Surf. Interface Analy.*, Vol. 36, 489-492 (2004).
13. L.F. Dong, **J. Jiao**, C.C. Pan and D.W. Tuggle, "Effects of Catalysts on the Internal Structures of Carbon Nanotubes and Corresponding Electron Field Emission Properties," *Appl. Phys. A*, Vol. 78, 9-14 (2004).
14. **J. Jiao**, E. Einarsson, D.W. Tuggle, L. Love, J. Prado, and G. Coia, "High-Yield Synthesis of Carbon Coils on Tungsten Substrates and Their Behavior in the Presence of an Electric Field," *J. Mater. Res.*, Vol. 18, No. 11, 2580-2587 (2003).

15. L.F. Dong, **J. Jiao**, M. Coulter, and L. Love, "Catalytic Growth of CdS Nanobelts and Nanowires on Tungsten Substrates," *Chem. Phys. Lett.*, Vol. 376, 653-658 (2003).
16. **J. Jiao**, L.F. Dong, S. Foxley, C. L. Mosher, and D. W. Tuggle, "Selected-Area Growth of Carbon Nanotubes by the Combination of Focused Ion Beam and Chemical Vapor Deposition Techniques," *Microscopy and Microanalysis*, Vol. 9, 516-521 (2003).
17. L.F. Dong, **J. Jiao**, D.W. Tuggle, J. Petty, S.A. Elliff, M. Coulter, "ZnO Nanowires Formed on Tungsten Substrates and Their Electron Field Emission Properties," *Appl. Phys. Letts.*, Vol. 82, 1096-1098 (2003).
19. **J. Jiao** "Challenges and Progresses on the Study of Carbon Nanotubes as Electron Field Emitters," Proceeding of the International Conference in Carbon 2002, CD RAM-I080, ISBN 7-900362-03-7/G.03, Shanxi Chunqiu Audio-Visual Press, (2002).
20. L.F. Dong, **J. Jiao**, S. Foxley, C.L. Mosher, D.W. Tuggle, "Effects of Hydrogen on the Formations of Carbon Nanotubes by Chemical Vapor Deposition," *J. Nanosci. Nanotech.*, Vol. 2, 155-160 (2002).
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23. R. Wang, J. Yang, Z. Zheng, M. D. Carducci, **J. Jiao**, and S. Seraphin, "Dendron-Controlled Nucleation and Growth of Gold Nanoparticles," *Angew. Chem. Int. Ed.*, Vol. 40, No. 3, 549-552 (2001).
24. **J. Jiao** and S. Seraphin, "Single-Walled Tubes and Encapsulated Nanoparticles: Comparison of Structural Properties of Carbon Nanoclusters Prepared by Three Different Methods," *Journal of Physics and Chemistry of Solids*, Vol. 61, 1055-1067 (2000).
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27. G.M. Li, **J. Jiao**, S. Seraphin, S. Raghavan, J.S. Jeon, "Masking Effect of Copper During Anisotropic Etching of Silicon in Buffered Hydrofluoric Acid Solutions," *J. Appl. Phys.*, Vol. 85, No. 3, 1857-1863, (1999).
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30. **J. Jiao** and S. Seraphin, "Carbon Encapsulated Nanoparticles of Co, Ni, Cu, and Ti," *J. Appl. Phys.*, Vol. 83, No. 5, 2442-2448, (1998).
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35. **J. Jiao** and S. Seraphin, "Internal Structure and Stability of Carbon Nanoclusters: Arc Discharge Preparation vs. CO Disproportionation," *Chem. Phys. Lett.*, Vol. 249, No. 1-2, 92-100 (1996).
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42. S. Seraphin, D. Zhou, **J. Jiao**, "Electron-Beam-Induced Structural Changes in Crystalline C<sub>60</sub> and C<sub>70</sub>," *Journal of Materials Research*, Vol. 8, No. 8, 1895-1899 (1993).



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44. S. Seraphin, D. Zhou, **J. Jiao**, J.C. Withers and R. Loutfy, "Yttrium Carbide in Nanotubes," *Nature*, Vol. 362, No. 6420, 503 (1993).
45. **J. Jiao**, D. Zhou, and S. Seraphin, "HREM Study of Carbon Nanoclusters of Different Shapes," *Microscopy Research and Technique*, Vol. 26, 168 (1993).
46. S. Seraphin, **J. Jiao**, and D. Zhou, "Carbon Nanoclusters Filled with Yttrium Compounds," *Microscopy Research and Technique*, Vol. 26, 168 (1993).
47. D. Zhou, **J. Jiao**, and S. Seraphin, "SEM Study of Carbon Nanotube Formation," *Microscopy Research and Technique*, Vol. 26, 168 (1993).
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50. **J. Jiao**, D. Zhou and S. Seraphin, "High-Resolution TEM Studies of Fullerenes," *Microscopy Research and Technique*, Vol. 22, 407 (1992).

***Refereed Proceeding Papers:***

51. **J. Jiao**, D. McClain, L.F. Dong, and R. Solanki, "Synthesis and Characterization of Single Crystalline Silicon Nanowires," *Proceedings of Microscopy and Microanalysis 2005*, Vol. 11, Supplement 2, 1876-1877 (2005).
52. D. McClain, L.F. Dong, C.C. Pan, **J. Jiao**, C. McCarter, D. Bahr, C. Richards, R. Richards, "Synthesis and Microanalysis of Aligned Carbon Nanotube Arrays," *Proceedings of Microscopy and Microanalysis 2005*, Vol. 11, Supplement 2, 1920-1921 (2005).
53. J.F. Wu, L.F. Dong, J. Petty, C.C. Pan, and **J. Jiao**, "Fabrication of Metal-Gated Carbon Nanotube Emitter Arrays Assisted by Focused Ion Beam and Chemical Vapor Deposition," *Proceedings of Microscopy and Microanalysis 2005*, Vol. 11, Supplement 2, 1956-1957 (2005).
54. T. Gutu, L.F. Dong, **J. Jiao**, G.L. Rorrer, C.H. Chang, C. Jeffryes, Q. Tian, "Characterization of Silicon-Germanium Oxide Nanocomposites Fabricated by the Marine Diatom *Nitzschia Frustulum*," *Proceedings of Microscopy and Microanalysis 2005*, Vol. 11, Supplement 2, 1958-1959 (2005).
55. S.H. Liu, C. Jeffryes, G.L. Rorrer, C.H. Chang, **J. Jiao**, and T. Gutu, "Blue Luminescent Biogenic Silicon-Germanium Oxide Nanocomposites," in *Biological and Bio-Inspired Materials and Devices*, edited by K.H. Sandhage, S. Yang, T. Douglas, A.R. Parker, E. DiMasi, *Mater. Res. Soc. Symp. Proc.* Vol. 873E, Warrendale, PA, K1.4.1-K1.4.6 (2005)

56. D. Chiang, P. Zifeng, L.F. Dong, and **J. Jiao**, "Atomically Resolved STM Images of CVD Grown Carbon Nanotubes," in *Scanning Probe and Other Novel Microscopies of Local Phenomena in Nanostructured Materials*, edited by S.V. Kalinin, B. Goldberg, L.M. Eng, and D. Huey, *Mater. Res. Soc. Symp. Proc.* 838E, Warrendale, PA, 010.2 (2005).
57. L.F. Dong, M. Coulter, N. Ford, and **J. Jiao**, "Synthesis, Characterization, and Growth Mechanism of Silicon Oxide Nanowires," in *Chemistry of Nanomaterial Synthesis and Processing*, edited by X. Peng, X. Feng, J. Liu, Z. Ren, and J.A. Voigt, *Mater. Res. Soc. Symp. Proc.* 879E, Warrendale, PA, Z10.9 (2005).
58. J.F. Conley, Jr., D. McClain, **J. Jiao**, W. Gao, D. Evans, and Y. Ono, "Characterization of Nanocones Grown During DC Magnetron Sputtering of an ITO Target," in *Chemistry of Nanomaterial Synthesis and Processing*, edited by X. Peng, X. Feng, J. Liu, Z. Ren, and J.A. Voigt, *Mater. Res. Soc. Symp. Proc.* 879E, Warrendale, PA, Z3.37 (2005).
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60. L.F. Dong, A. Maiz, **J. Jiao**, "Synthesis and Characterization of  $\text{WO}_x$  Nanowires and Their Conversion to  $\text{WS}_2$  Nanotubes," in *Self-Organized Processes in Semiconductor Heteroepitaxy*, edited by A.G. Norman, R.S. Goldman, R. Netzel, G.B. Stringfellow, *Mater. Res. Soc. Symp. Proc.* Vol. 794, Warrendale, PA, T3.11 (2004).
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71. L.F. Dong, **J. Jiao**, C.L. Mosher, and S. Foxley, "Growth of Carbon Nanotubes with Controlled Morphologies," *Mat. Res. Soc. Symp. Proc.*, Vol. 728, S8.21.1 – S8.21.6, (2002).
72. **J. Jiao** and F.Q. Tang, "High Resolution TEM and EDX Investigation of Metal Coated Nanoparticles," *Microscopy and Microanalysis: Proceedings of Microscopy and Microanalysis 2001*, Vol. 7, 388-389 (2001).
73. L.F. Dong, **J. Jiao**, D.W. Tuggle, and S. Foxley, "Synthesis and Characterization of Carbon Nanotubes on Porous Silicon Substrate," *Proceedings of Microscopy and Microanalysis 2001*, Vol. 7, 398-399 (2001).
74. T. Wilson, **J. Jiao**, S. Seraphin, B. Johnson, M. Anc, and B. Cordts, "Effects of Protective Capping on Ultra-Thin SIMOX Structures," *Proceedings of Microscopy and Microanalysis 1999*, Vol. 5, 744-745 (1999).
75. B. Johnson, **J. Jiao**, S. Seraphin, T. Yan, T. Wilson, M. Anc, and B. Cordts, "Control of Si-Island Free Ultra-Thin SIMOX Structures by Implant Energy and Oxygen Dose," *Proceedings of Microscopy and Microanalysis 1999*, Vol. 5, 746-747 (1999).
76. **J. Jiao**, B. Johnson, and S. Seraphin, "Synthesis of Carbon-Coated Hafnium Carbide Nanoparticles," *Proceedings of the 14<sup>th</sup> International Congress on Electron Microscopy (ICEM14)*, Vol. 3, 93 (1998).
77. S. Seraphin, **J. Jiao**, C. Beeli, P.A. Stadelmann, J.-M. Bonard, A. Chatelain, "Electron Holography of Carbon-Coated Ferromagnetic Nanoclusters," *Proceedings of the 14<sup>th</sup> International Congress on Electron Microscopy (ICEM14)*, Vol. 1, 569 (1998).
78. J.-M. Bonard, S. Seraphin, C. Beeli, J.-E. Wegrowe, T. Stockli, **J. Jiao**, P.A. Stadelmann, A. Chatelain, "Production and Characterization of Carbon Encapsulated Ferromagnetic Cobalt Particles," *Fullerenes: Recent Advances in the Chemistry and Physics of Fullerenes and Related Materials. Proceedings of the 193th Meeting of the Electrochemical Society*, (1998).

79. L.P. Allen, M.J. Anc, B. Dolan, **J. Jiao**, B. Guss, and S. Seraphin, "Buried Oxide Densification for Low Power, Low Voltage CMOS Application," *Proceedings 1998 IEEE International SOI Conference*. October 5-8, Stuart, FL, IEEE, Piscataway, NJ, 1998, p. 39.
80. **J. Jiao** and S. Seraphin, "Carbon-Coated Fe, Co, and Ni Ferromagnetic Nanoparticles Prepared by a Modified Arc Discharge," *Proceedings of the Symposium on Recent Advances in the Chemistry and Physics of Fullerenes and Related Materials*, Edited by K.M. Dadish, R. Ruoff, the Electrochemical Society Inc., Vol. 96-10, 688-695 (1996).
81. M.J. Anc, **J. Jiao**, S. Seraphin, J. Kirchhof, P.J. McMarr, H.L. Hughes, "High Quality Low-Dose Low-Energy SIMOX Implanted in High Current Oxygen Implanter," *Proceedings 1998 IEEE International SOI Conference*. October 5-8, Stuart, FL, IEEE, Piscataway, NJ, 1998, p. 41.
82. K. Parvin, S.P. Weathersby, S. Awadallah, R. LaDuca, R.S. Ruoff, S. Subramoney, P. Van Kavelaar, P.E. Nolan, **J. Jiao**, A.H. Cutler, D.C. Lynch, and S. Seraphin, "Magnetic Studies of Nickel Nanoparticles in Carbon Nanotubes and Carbon Polyhedra Synthesized by Chemical Methods," in *Fullerenes: Recent Advances in the Chemistry and Physics of Fullerenes and Related Materials*, R.S. Ruoff and K.M. Kadish, eds, *Proceedings of the Electrochemical Society*, Vol. 95-10, 570-576 (1995).
83. **J. Jiao**, P.E. Nolan, S. Seraphin, A.H. Cutler, and D.C. Lynch, "Preparing Carbon Clusters by Catalytic Disproportionation of Carbon Monoxide," in *Fullerenes: Recent Advances in the Chemistry and Physics of Fullerenes and Related Materials*, R.S. Ruoff and K.M. Kadish, eds, *Proceedings of the Electrochemical Society*, Vol. 95-10, 667-673 (1995).
84. **J. Jiao**, D. Zhou, and S. Seraphin, "HRTEM Studies of Structural Phenomena and Growth Mechanisms in Carbon Nanoclusters," *Proceedings of the International Congress on Electron Microscopy (ICEM)*, Vol. 13, 339 (Paris 1994).
85. D. Zhou, **J. Jiao**, and S. Seraphin, "TEM of Single-Walled Carbon Nanotubes," *Proceedings of the International Congress on Electron Microscopy (ICEM)*, Vol. 13, 323 (Paris 1994).
86. **J. Jiao**, "Structural Phenomena in the Growth of Carbon Nanotubes," *Proceeding of the Electron Microscopy of America*, Vol. 51, 752 (1993).
87. S. Seraphin, D. Zhou, and **J. Jiao**, "Insertion of Yttrium Carbide into Carbon Nanoclusters by Vapor Transport During Growth," *Proceeding of the Electron Microscopy of America*, Vol. 51, 758 (1993).
88. D. Zhou, S. Seraphin, and **J. Jiao**, "SEM Study of Structure and Formation of the Carbon Clusters in the Arc-Discharge Deposits," *Proceeding of the Electron Microscopy of America*, Vol. 51, 756 (1993).
89. S. Seraphin, D. Zhou, **J. Jiao**, L.D. Lamb and D.R. Huffman, "High-Resolution TEM of Fullerenes of Different Sizes," *Proceeding of the Electron Microscopy of America*, Vol. 50, 298 (1992).

***Non-Refereed Publications:***

90. H. Oporta, L.F. Dong, **J. Jiao**, "Electrical Characterization of Aligned Single-Walled Carbon Nanotubes," *Proceeding (p. 29) of the 2005 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Troutdale, Oregon, September 15-16, 2005.
91. D. McClain, L.F. Dong, P. Chu, **J. Jiao**, C. McCarter, D. Bahr, C. Richards, R. Richards, "Synthesis and Electrical Characterization of Aligned Carbon Nanotube Bundles," *Proceeding (p. 28) of the 2005 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Troutdale, Oregon, September 15-16, 2005.
92. J. Lo, L. Dong, **J. Jiao**, "Effects of Organic Molecules on Dispersion and Dielectrophoresis Alignment of Single-Walled Carbon Nanotubes," *Proceeding (p. 27) of the 2005 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Troutdale, Oregon, September 15-16, 2005.
93. T. Gutu, **J. Jiao**, T. Qin, C. Jeffries, G. L. Rorrer, C.-H. Chang, "Biosynthesis and Electron Microscopy Characterization of Nanocomposites in Diatom *Nitzschia*," *Proceeding (p. 25) of the 2005 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Troutdale, Oregon, September 15-16, 2005.
94. A. Grill, L.F. Dong, **J. Jiao**, "Synthesis, Purification and Characterization of Carbon Nanotubes," *Proceeding (p. 24) of the 2005 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Troutdale, Oregon, September 15-16, 2005.
95. L.F. Dong, J. Bush, V. Chirayos, H. Oporta, J. Lo, **J. Jiao**, "Dielectrophoretic Controlled Alignment of 1 D Nanostructures," *Proceeding (p. 15) of the 2005 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Troutdale, Oregon, September 15-16, 2005.
96. J.F. Wu, L. Dong, **J. Jiao**, "Effects of Catalysts on the Fabrication of Metal-Gated Carbon Nanotube Emitter Arrays," *Proceeding (p. 32) of the 2005 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Troutdale, Oregon, September 15-16, 2005.
97. V. Ho, J. Hedberg, **J. Jiao**, "Dispersion of Carbon Nanotubes via Single-Stranded DNA," *Proceeding of the Northwest Undergraduate Science Research Conference*, Portland, Oregon, April 9, 2005.
98. C. Pan, **J. Jiao**, "Effects of Iron, Nickel and Cobalt Catalysts on Aligned Carbon Nanotubes," *Proceeding of the 2004 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Richland, Washington, June 16-17, 2004.
99. J. Petty, L.F. Dong, **J. Jiao**, "Field Emission Study of Carbon Nanotube Synthesis with the Assistance of FIB," *Proceeding of the 2004 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Richland, Washington, June 16-17, 2004.
100. J. Hedberg, **J. Jiao**, "Controlled Dispersion and Purification of Carbon Nanotubes on Various Substrate Surfaces," *Proceeding of the 2004 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Richland, Washington, June 16-17, 2004.
101. J. Green, **J. Jiao**, "Synthesis and Characterization of Molybdenum Sulfide Nanostructures," *Proceeding of the 2004 Conference of the Pacific Northwest Chapter of the American Vacuum*

Society, Richland, Washington, June 16-17, 2004.

102. C.C. Pan, **J. Jiao**, "Synthesis and Characterization of Aligned Carbon Nanotubes," *Proceeding of the Northwest Undergraduate Science Research Conference*, Portland, Oregon April 10, 2004.
103. J. Green, **J. Jiao**, "Synthesis and Characterization of Molybdenum Sulfide Nanostructures," *Proceeding of the Northwest Undergraduate Science Research Conference*, Portland, Oregon, April 10, 2004.
104. **J. Jiao**, "Written Testimony Before the U.S. Senate Committee on Commerce, Science, and Technology on S. 189, The 21th Century Nanotechnology Research and Development Act," published in U.S. Senate's web page at <http://commerce.senate.gov/pdf/Jiao050103.pdf>, (2003).
105. **J. Jiao**, "High Resolution TEM and EDX Characterization of Nanowires and the Investigation of Their Electron Field Emission Properties" (invited paper), *Proceeding (p. 16-17) of 30<sup>th</sup> Annual Meeting of the Microscopy Society of Canada*, Vancouver, British Columbia, June 4-6, 2003.
106. T. Gushtyuk, L.F. Dong, and **J. Jiao**, "Synthesis of Tungsten Oxide and Cadmium Sulfide Nanowires Using Thermal Evaporation Method," *Proceeding (p. 10) of The Northwest Undergraduate Science Research Conference*, Portland, Oregon April 5, 2003.
107. T. J. McKinney, **J. Jiao**, D. W. Tuggle, J. Petty, and L.F. Dong, "Photonic and Electron Emission Properties Displayed by Single-Walled and Multi-Walled Carbon Nanotubes," *Proceeding (p. 54) of the 2002 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Vancouver, Washington, September 11-12, 2002.
108. L.F. Dong, **J. Jiao**, M. Coulter, S.A. Elliff, J. Petty, L. Love, T. Mckinney, D.W. Tuggle, "Catalytic Growth of Inorganic Semiconductor Nanowires with Controlled Properties," *Proceeding (p. 55) of the 2002 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Vancouver, Washington, September 11-12, 2002.
109. L.F. Dong, **J. Jiao**, S. A. Elliff, "Catalytic Growth of Zinc Oxide Nanowires by Chemical Vapor Deposition," *Proceeding (p. 34) of the 2002 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Vancouver, Washington, September 11-12, 2002.
110. E. Einarsson, **J. Jiao**, J. Prado, G.M. Coia, "Growth of Carbon Nanocoils and Microcoils on Tungsten Substrates," *Proceeding (p. 35) of the 2002 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Vancouver, Washington, September 11-12, 2002.
111. J. Petty, L.F. Dong, **J. Jiao**, "Synthesis of Carbon Nanotubes Field Emitters Using Two Catalyst Deposition Methods," *Proceeding (p. 50) of the 2002 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Vancouver, Washington, September 11-12, 2002.
112. L. Love, L.F. Dong and **J. Jiao**, "Growth of Cobalt Catalyzed Carbon Nanotubes on Various Substrates," *Proceeding (p. 49) of the 2002 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Vancouver, Washington, September 11-12, 2002.

113. M. Coulter, L.F. Dong, **J. Jiao**, "Co-Synthesis of Silicon Oxide and Cadmium Sulfide Nanowires," *Proceeding (p. 28) of the 2002 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Vancouver, Washington, September 11-12, 2002.
114. S. Foxley, C. L. Mosher, L. Dong, **J. Jiao**, "Aligned and Patterned Growth of Multi-Walled Carbon Nanotubes," *Proceeding of the 2001 Conference of the Pacific Northwest Chapter of the American Vacuum Society*, Forest Grove, Oregon, September 24, 2001.
115. **J. Jiao** and T.F. Qiong, "Characterization and Synthetic Design of Metal and Metal Oxide Nanoparticles," extended abstract published in the *Proceeding of the International Union of Materials Research Societies – 6<sup>th</sup> International Conference in Asia*, p. C6.5, Hong Kong, China, July 23-26, 2000.
116. **J. Jiao**, "Roles of Fe, Co, and Ni in the Formation of Single-Walled Carbon Nanotubes and Encapsulated Nanoparticles," extended abstract published in the *Proceeding of the American Vacuum Society (AVS) 46<sup>th</sup> International Symposium and the Topical Conference on Emerging Opportunities and Issues in Nanotubes and Nanoelectronics*, p. 144, Seattle, WA Oct. 25-29, 1999.
117. **J. Jiao** "Comparison of the Structural Properties of Carbon Nanoclusters Prepared by Three Different Methods," *Proceeding of the 5<sup>th</sup> IUMRS International Conference on Advanced Materials*, Vol. 1, 141 (1999).

#### **Presentations at Professional Meetings**

##### ***Internationally Invited Talks, Seminars, and Workshops:***

- Gave an invited seminar entitled "Controlled Fabrication of Nanotubes and Nanowires and Their Potential Applications" at the Chinese Academy of Science, Technical Institute of Physics and Chemistry, Beijing, China, July 19, 2005.
- Gave an invited seminar entitled "The Novel Structural Properties of DNA-Nanotube Hybrids" at Shanghai Jiao Tong University, Shanghai, China, July 12, 2005.
- Gave an invited seminar entitled "Building Blocks for Electronic Nanodevices: Controlled Fabrication and Characterization of Carbon Nanotubes and Nanowires Transistors" at East China Normal University, Shanghai, China, July 11, 2005.
- Gave an invited keynote talk entitled "Systematic Investigation of the Formation of Metallic Oxide and Semiconductor Nanowires and Their Field Emission Properties" at the XIII International Materials Research Congress in Cancun, Mexico, August 22-26, 2004.
- Gave an invited keynote talk entitled "Electron Field Emission Behavior of Carbon Nanotubes and Nanocoils with Different Morphologies" at the 8<sup>th</sup> IUMRS (International Union of Materials Research Society) International Conference on Advanced Materials, Yokohama, Japan, October 8-13, 2003.
- Gave an invited seminar entitled "Semiconductor Nanowires and Their Electron Field Emissions" at the Chinese Academy of Science, Technical Institute of Physics and Chemistry, Beijing China, November, 21, 2003.

- Gave an invited lecture entitled “An Introduction to the Nanoscience and Nanotechnology” at S.Y. Technology, Engineering and Construction Co., Ltd (A CEEDI Company), Beijing, China, November 22, 2003.
- Gave an invited keynote talk entitled “High Resolution TEM and EDX Characterization of Nanowires and the Investigation of Their Electron Field Emission Properties” at the 30<sup>th</sup> Annual Meeting of the Microscopy Society of Canada, Vancouver, British Columbia, Canada, June 4-6, 2003.
- Gave an invited keynote review talk entitled “Challenges and Progresses on the Study of Carbon Nanotubes as Electron Field Emitters” at the International Conference on Carbon, Beijing, China, September 15-19, 2002.
- Gave an invited seminar entitled “Synthesis and Characterizations of Semiconductor Nanowires” at the Physics Department and the Materials Science and Engineering Department, Fudan University, Shanghai, China, September 1, 2002.
- Gave an invited seminar on “Tailoring Carbon Nanoclusters to Desired Properties” at the Chinese Academy of Science, Technical Institute of Physics and Chemistry. Beijing, China, July 14, 2000.
- Gave an invited keynote talk entitled “Characterization and Synthetic Design of Metal and Metal Oxide Nanoparticles” at the International Union of Materials Research Societies – 6<sup>th</sup> International Conference in Hong Kong, China, July 23-26, 2000.
- Gave an invited seminar on “High Resolution Electron Microscopy Characterization of Nanoscaled Materials” at the Research Center for Nanostructured Materials, Qingdao Institute of Chemical Technology, Qingdao, China. August 2, 2000.
- Gave an invited review talk on “Comparison of the Structural Properties of Carbon Nanoclusters Prepared by Three Different Methods” at the 5<sup>th</sup> IUMRA - ICAM’99 (International Union of Materials Research Societies - International Conference on Advanced Materials), Beijing, China, June 13 - 18, 1999.
- Gave an invited talk on “HREM Studies of Structural Phenomena and Growth Mechanisms in Carbon Nanoclusters,” at the 13<sup>th</sup> International Congress for Electron Microscopy, Paris, France, July 17 - 24, 1994.

***Nationally Invited Talks, Seminars, and Workshops:***

- Invited to give a workshop entitled “Carbon Nanotubes – Technology and Applications” at Silicon Valley Technical Institute, San Jose, California, February 13-14, 2006. The audiences were the Engineers and Scientists from the Bay area companies including Sun Microsystems, Applied Materials, and Namiki Precision of California, to mention just a few.
- Invited by the National Academy of Sciences to attend the panel discussion on advances and opportunities in related cutting edge research at the 17<sup>th</sup> Frontiers of Science Symposium held in the Academy’s Arnold and Mabel Beckman Center, Irvine, California, October 27-29, 2005
- Invited to give a talk entitled “Nanoscience and Nanotechnology Research and Education in Action”



at Pacific Northwest Venture Capital Symposium, held at the Bellevue Hyatt Hotel in Bellevue, WA, September 12-13, 2005.

- Invited to give two short courses entitled “How to Prepare a Winning Proposal: Obtaining Funds from the National Science Foundation,” and “Introduction to the Electron Microscopy and Microanalysis Facility at Portland State University” at the Micro- Nano- Breakthrough Conference, Portland, Oregon, July 25-28, 2005.
- Gave an invited seminar entitled “Synthesis and Characterization of Nanostructures: Developing Building Blocks for Electronic Devices” at the Oregon Nanosciences and Microtechnology Institute, Corvallis, Oregon, February 9, 2005.
- Gave an invited, featured speech: “Microscopy and Microanalysis Research and Education at PSU- Inspiring Female and Minority Students Majoring in Science and Engineering” at the Women in Science Breakfast at the 62<sup>th</sup> Annual Conference of the Microscopy Society of America, Savannah, Georgia, August 1-5, 2004.
- Gave an invited talk entitled “Carbon Nanotubes and Semiconductor Nanowires as Electron Field Emitters” at the Micro- Nano- Breakthrough Conference, Sheraton Airport Hotel, Portland, Oregon, July 28-29, 2004.
- Gave an invited keynote talk entitled “A Review of Nanofabrication Efforts and Challenges” at the National Science Foundation Workshop on “Control and System Integration of Micro- and Nano-Scale Systems,” Arlington VA, March 29-30, 2004.
- Gave an invited seminar entitled “Synthesis and Characterization of Semiconductor Nanowires” at the University of Texas at Austin, August 7, 2003.
- Gave an invited seminar entitled “Carbon Nanotubes and Semiconductor Nanowires as Building Blocks for Electronic Devices” at Hewlett-Packard Company, Corvallis, Oregon, July 31, 2003.
- Gave an invited seminar entitled: “Synthesis and Characterization of Carbon Nanotubes and Semiconductor Nanowires as Electron Field Emitters” at the Physics Department, Linfield College, October 19, 2002.
- Gave an invited seminar entitled: “Electron Field Emission and Light Emission of Carbon Nanotubes ” at the Chemistry Department, West Washington University, July 19, 2002.
- Gave an invited seminar entitled: “Carbon Nanotubes as Electron Field Emitters” at the Physics Department, Oregon State University, March 30, 2002.
- Invited to the Arizona Imaging and Microanalysis Society (AIMS) to attend a panel discussion on electron microscopy and microanalysis for advanced materials research and chaired a session at AIMS annual spring meeting in Tucson, AZ, February 10, 2000.
- Series of invited lectures on fullerene-related research at the University of Puerto Rico, in Mayaguez Campus, Puerto Rico, May 15 - 25, 1993.

***Nationally and Internationally Contributed Talks:***

- Presented **four papers** entitled “Synthesis and Characterization of Single Crystalline Silicon Nanowires,” “Synthesis and Microanalysis of Aligned Carbon Nanotube Arrays,” “Fabrication of Metal-Gated Carbon Nanotube Emitter Arrays Assisted by Focused Ion Beam and Chemical Vapor Deposition,” and “Characterization of Silicon-Germanium Oxide Nanocomposites Fabricated by the Marine Diatom *Nitzschia Frustulum*,” at Microscopy and Microanalysis 2005 - The 63rd Annual Conference of Microscopy Society of America, Honolulu, Hawaii, July 31-August 4, 2005.
- Presented **two papers** entitled “Methods for Dispersion and Alignment of Single-walled Carbon Nanotubes and Effects on Their Structural and Electronic Properties” and “Fabrication and Electron Microscopy Characterization of Metal-Gated Carbon Nanotube Emitter Arrays” at the 3rd International Conference on Materials for Advanced Technologies (ICMAT 2005) and the 9<sup>th</sup> International Conference on Advanced Materials (ICAM 2005), Singapore, July 3-8, 2005.
- Presented **three papers** entitled “Effects of Preparation Parameters on the Formation of ZnO Nanostructures Characterized by FESEM/HRTEM and EDS,” “Morphology and Field Emission Characteristics of Carbon Nanotubes Grown using Pt Catalysts,” and “Electron Microscopy and Microanalysis Study of Conversion of WO<sub>x</sub> Nanowires into WS<sub>2</sub> Nanotubes,” at Microscopy and Microanalysis 2004 - The 62nd Annual Conference of Microscopy Society of America, Savannah, Georgia, August 1-5, 2004.
- Presented **a paper** entitled “High Resolution Electron Microscopy and Spectroscopy Characterization of Tungsten Oxide Nanowires” at Microscopy and Microanalysis 2003 - The 61st Annual Conference of Microscopy Society of America, San Antonio, Texas, August 3-7, 2003.
- Presented **two papers** entitled “Synthesis of SiO<sub>2</sub> Nanowires and CdS/SiO<sub>2</sub> Composite Nanowires and Investigation of Their Electron Field Emission Properties” and “Synthesis of Carbon Microcoils and Nanocoils on Various Substrates” at the Materials Research Society Annual National Conference, Boston, Massachusetts, December 2-6, 2002.
- Presented **a paper** entitled “Focused Ion Beam Assisted Nanofabrication – Patterned Growth of Carbon Nanotubes” at Microscopy and Microanalysis 2002 - The 60th Annual Conference of Microscopy Society of America, Quebec City, Quebec, Canada, August 5-8, 2002.
- Presented **a paper** entitled “Correlations of the Microstructures of the Carbon Nanotubes and Their Field Emission Properties” at the Materials Research Society Annual National Conference, Boston, Massachusetts, November 26-30, 2001.
- Presented **a paper** entitled “High Resolution TEM and EDX Investigation of Metal Coated Nanoparticles” at Microscopy and Microanalysis 2001 - The 59th Annual Conference of Microscopy Society of America, Long Beach, California, August 5-9, 2001.
- Presented **a paper** entitled “Roles of Fe, Co, and Ni in the Formation of Single-Walled Carbon Nanotubes and Encapsulated Nanoparticles” at the American Vacuum Society (AVS) 46<sup>th</sup> International Symposium and the Topical Conference on Emerging Opportunities and Issues in Nanotubes and Nanoelectronics, Seattle, Washington Oct. 25-29, 1999.
- Presented **a paper** on “Defects in Ultra-Thin SIMOX: Microstructure vs. Processing Conditions” at the 5<sup>th</sup> IUMRA - ICAM’99 (International Union of Materials Research Societies - International Conference on Advanced Materials), Beijing, China, June 13 - 18, 1999.

## Honors, Grants, Fellowships, and Patents

### **Honors:**

- Recipient of 2004 Presidential Early Career Award for Scientists and Engineers (PECASE). This award is cited as the nation's highest honor for professionals at the outset of their research careers whose work shows exceptional promise for leadership at the frontiers of scientific knowledge. June 13, 2005.
- Awarded the AWSEM's "Certificate of Recognition" in recognition of the recipient's outstanding contribution of time, effort and enthusiasm as a Site Visit Volunteer for the 2004-2005 AWSEM (Advocates for Women in Science, Engineering and Mathematics) Program. May 2005.
- Recipient of the NSF's CAREER Award which is designed to recognize and support the early career-development activities of those teacher-scholars who are most likely to become the academic leaders of the 21<sup>st</sup> century. June 1, 2004.
- Recognized as one of the 50 great leaders in *Oregon Business*' "go-to team" for 2005, by *Oregon Business Magazine*, Vol. 27, No. 10, 22, October 4, 2004.
- Recipient of John Eliot Allen Outstanding Teaching Awards, College of Liberal Arts and Sciences, Portland State University, June 4, 2004.
- Recipient of Outstanding Mentor Awards of 2003/2004 Siemens Westinghouse Competition: Math: Science: Technology Winner, June 23, 2004.
- Invited to be a member of the National Honor Society of Phi Kappa Phi and inducted by the Portland State University Chapter, May 27, 2004.
- Invited by the United States Senators Committee on Commerce, Science, and Transportation, to testify in front of the full Committee in Washington, D.C. on the legislation – S. 189: "The 21<sup>st</sup> Century Nanotechnology Research and Development Act." May 1, 2003.
- Honorary professor at Physics Department, Liaocheng University, Liaocheng, China. Honored in September 2002.
- Honorary professor at Research Center for Nanostructured Materials, Qingdao Institute of Chemical Technology, Qingdao, China. Honored in the year 2000.
- Presidential Scholar of the Microscopy Society of America, 1993.
- Excellence in Teaching Award, Shandong University, 1986, 1988.

### **Grants (received):**

- **External grant (\$500,000):** "Acquisition of a Dual Beam Focused Ion Beam System: Advancing Research and Education at Portland State University and at the Oregon Nanoscience and Microtechnologies Institute," awarded by the National Science Foundation. Funding period: July 2005 – June 2006. Serves as principal investigator.

- **External Grant (\$140,000):** “Nanostructures for Electronics Device Applications,” awarded by Sharp Labs of America. Funding period: October 2004 – October 2006. Serves as principal investigator.
- **External grant (\$1,300,000):** “NIRT: Whole-Cell Biosynthesis of Nanostructured Metal Oxide Semiconductors,” collaborated with two OSU colleagues. My share of this grant is \$400,000. Awarded by the National Science Foundation. Funding period: August 2004 – July 2008. Serves as co-principal investigator.
- **External grant (\$1,000,000):** “NIRT: Nanotube based structures for high resolution control of thermal transport,” collaborated with four WSU colleagues. My share of this grant is \$216,000. Awarded by the National Science Foundation. Funding period: August 2004 – July 2008. Serves as co-principal investigator.
- **External grant (\$400,000):** “CAREER: A Novel Approach for Controlled Fabrication of Micro-Gated Carbon Nanotube Field Emitter Arrays and Their Electrical Property Characterizations,” awarded by the National Science Foundation. Funding period: July 2004 – June 2009. Serves as principal investigator.
- **External grant (\$207,000):** “REU Site: Application of Microscopy and Microanalysis to Multidisciplinary Research,” awarded by the National Science Foundation. Funding period: February 2004– January 2007. Serves as principal investigator (This is a renewed grant).
- **External grant (\$300,000):** “Systematic Investigation of Single-Walled Carbon Nanotubes Properties, Structure, Composition and Resistivity,” awarded by the Intel Corporation: July 2003 – June 2006. Serves as principal investigator.
- **External grant (\$23,333):** “A Collaborative Effort on High Resolution TEM Investigation of Semiconductor Materials,” awarded by LSI Logic: June 2003 – December 2003. Served as principal investigator.
- **External grant (\$475,000):** “The Advancement of Portland State University’s Multi-Disciplinary Materials Research,” awarded by the M.J. Murdock Charitable Trust: August 2002 – July 2003. Served as principal investigator.
- **External grant (\$180,000):** “Integration of Nanoscience, Research, and Outreach –Systematic Tailoring of Carbon Nanotubes to Designed Electronic Properties,” awarded by the National Science Foundation. Funding period: August 2002 – July 2005. Served as principal investigator.
- **External grant (\$35,000):** “A Novel Method for Position-Controlled Growth of Carbon Nanotubes: Investigation of the Field Emission Properties of Carbon Nanotubes,” awarded by the Petroleum Research Foundation – American Chemical Society. Funding period: June 2002 – May 2004. Served as a principal investigator.
- **External grant (\$189,000):** “REU Site: Application of Microscopy and Microanalysis to Multidisciplinary Research,” awarded by the National Science Foundation. Funding period: June 2001– May 2004. Served as principal investigator.
- **External grant (\$485,741):** “A Collaborative Effort for Acquisition of a Tecnai F-20 Field Emission

High Resolution Transmission Electron Microscope,” awarded by the FEI Company. Funding period: July 2001 – June 2002. Served as principal investigator.

- **External grant (\$376,366):** “A Collaborative Effort for Acquisition of a FEI Sirion Field Emission High Resolution Scanning Electron Microscope,” awarded by the FEI Company. Funding period: June 2002 – May 2003. Served as principal investigator.
- **External grant (\$4,000):** “High Resolution TEM Investigation of Nanostructures at the National Center for Electron Microscopy (NCEM),” awarded by the NCEM at Lawrence Berkeley National Laboratory. Funding period: July 2000 – June 2002. Served as principal investigator.
- **Internal grant (\$130,000):** “Initiation of Basic Infrastructure for the Development of Nanotechnology at PSU,” awarded by the Office of Research and Sponsored Projects at PSU. Funding period: June 2004 – May 2005. Served as co-principal investigator.
- **Internal grant (\$12,000):** “Training Undergraduate Students in the Cutting Edge Research - Undergraduate Research and Creative Grant,” awarded by the Office of Academic Affairs. Funding period: February 2002– June 2006. Serves as the project director.
- **Internal grant (\$3,500):** “2002-03 Departmental Engagement Project – Let Physics Serve the City,” awarded by the Center for Academic Excellence. Funding period: November 2002 – May 2003. Served as co-principal investigator.
- **Internal grant (\$3,000):** “Undergraduate Research Projects: Development of Tungsten and Carbon Nanotube Electron Field Emitters,” awarded by the Office of Academic Affairs. Funding period: January 2003 – December 2003. Served as principal investigator and undergraduate research supervisor.
- **Internal grant (\$1,168,000):** “Acquisition of a High Resolution Transmission Electron Microscope,, awarded by Portland State University. Funding period: July 2001 – June 2002. Served as principal investigator.
- **Internal grant (\$7,000):** “Building a Centralized TEM Facility at PSU: Acquisition of a Model 150 Dimpling Grinder,” awarded by the Faculty Development Committee, Portland State University. Funding period: July 2001–June 30, 2000. Served as a principal investigator.
- **Internal grant (\$1,500):** “Building a Centralized TEM Facility at PSU: Acquisition of a Precision Sectioning Saw,” awarded by the Office of Academic Affairs, Portland State University. Funding period: July 2000 – June 2001. Served as principal investigator.
- **Internal grant (\$4,500):** “Site for REU: Electron Microscopy and Microanalysis of Materials Research,” awarded by the Faculty Development Committee. Funding period: July 2000 – June 2001. Served as principal investigator.
- **Internal grant (\$500):** “A Novel Approach to Teaching Physical Metallurgy for Engineers,” awarded by the Office of Academic Affairs. Funding period: April 2000 – March 2001. Served as principal investigator.

***In-kind equipment donations received:***

- **Received sample preparation equipment donation from Gatan (estimated value: \$29,990):** “Ultrasonic disc cutter, specimen lapping kit, specimen mounting hot plate, dimple grinder w/autotermiator, electronic micrometer & stereo microscope,” received September 30, 2002.
- **Received an electron microscope donation from Intel (estimated value: \$150,000):** “JEOL 2000FX Transmission Electron Microscope,” received January 10, 2004.
- **Received ultra high vacuum chamber donation from OMEGA Inc. and Reed College (estimated value: \$10,000):** “Ultra high vacuum chamber for building an electron field emission microscope,” received January 2004.
- **Received equipment donation from Pacific Northwest National Lab (estimated value: \$65,415):** “Computer Controlled VCR Ion Beam Milling Machine XLA2000,” received May 1, 2001.
- **Received dark room equipment donation from Intel (estimated value: \$1775):** “Automated enlarger, developer, light table, safety light settings, and rotation light proof door, etc.” received January 31, 2001.

***Fellowships:***

- Visiting Scientist Fellowship from the National Center for Electron Microscopy, Lawrence Berkeley National Laboratory, June 2000 – June 2002.
- User's Scholarship for conducting electron holography research on nanostructural materials at the Oak Ridge National Laboratory, January 20 - 27, 1996.
- Graduate College Fellowship, University of Arizona, 1994 - 1995.

***Patents:***

- **J. Jiao, D. W. Tuggle, L. F. Dong, and S. Foxley, "Method for Synthesizing Nanoscale Structures in Defined Locations,"** U.S. and International Patent (patent application No. 60/400,897), disclosed August 2002 and filed July 21, 2003. Pending.
- **J.F. Conley, Jr., Y. Ono, J. Green, and J. Jiao, “Method to Generate Electroluminescence,”** disclosed June 2005.
- **J.F. Conley, Y. Ono, and L. Stecker, V.H. Hsu, J. Green, L.F. Dong, and J. Jiao, “Method to Improve Field Emission of Carbon Nanotubes,”** disclosed March 2005.

**Other Research and Creative Achievements**

- **Contributions to Knowledge in Related Fields:** Over the last twelve years, I have established myself as an important contributor to the field of nanoscience and nanotechnology, especially in the areas of carbon nanotubes, nanowires, nanoparticles and electron microscopy and spectroscopy characterization of materials. My original contributions to the research in these areas are documented in more than 80 publications and have drawn invitations to give talks at international and national conferences and workshops. A cited reference search by my student using science citation index suggests that a number of refereed journal papers that I authored or co-authored were cited by other

colleagues more than **670 times** during 1993-2005. Although most of the papers published during 1999-2005 listed my students as the first, second and third authors, I served as the corresponding author for all the papers published by my group.

- **Establishment of Multidisciplinary Collaborations:** Through my research, I have collaborated with colleagues from local high-tech companies such as Intel, FEI, LSI Logic, Sharp Labs of America and local research institutions, including: Oregon State University, Oregon Graduate Institute (now part of Oregon Health & Science University), Washington State University and the Oregon Nanoscience and Microtechnologies Institute (ONAMI), a research consortium between PSU, OSU, University of Oregon, Pacific Northwest National Laboratory and others. The impact of these collaborations is reflected by the large number of funded research projects and publications that these partnerships produced.
- **Improvement of Research Infrastructures:** Since joining PSU in the fall of 1999, I have been allocated a total of more than \$5 million in funding from the National Science Foundation (NSF), the Petroleum Research Foundation, the Murdock Foundation, PSU and various corporate partners for the establishment of an integrated research, education and outreach program in nanoscience and nanotechnology. I have led this significant effort by collaborating with other colleagues to acquire four state-of-the-art electron microscopes. In addition, I have received donations from local high-tech industry and national laboratories, paving the way for the establishment of a first-class electron microscopy and nanofabrication center at PSU. This multi-user facility consists of a FEI Tecnai F-20 FETEM equipped with an embedded scanning transmission electron microscope (STEM), GIF and energy dispersive x-ray spectrometer (EDS), a JEOL 2000FX TEM equipped with EDS, a FEI Sirion FESEM equipped with EDS, a FEI Strata 237 Dual Beam FIB equipped with STEM, EDS and TEM sample preparation capabilities, a FEI 611 FIB system equipped with a secondary ion mass spectrometer (SIMS), and a well-equipped specimen preparation laboratory. The facility serves not only PSU's researchers and students, but also those from other universities, as well as technical personnel from local high-tech companies.
- **Preparation of Highly Qualified Graduate Students:** From 1999-2005, I have graduated one Ph.D., Lifeng Dong, who is continuing his postdoctoral research in my group, and four M.S. students. Among the four M.S. graduates, Bob McGeary and Sean Kellogg are working successfully as an enterpriser and an engineer in a high-tech company, respectively. Erik Einarsson and James Hedberg each won full fellowships to continue their Ph.D. study at the University of Tokyo in Japan, and at McGill University in Canada, respectively. Currently, my group consists of one postdoctoral researcher, three Ph.D. students, four M.S. students and five undergraduate students. Among these students, several have won international, national, collegial, and departmental research and academic awards or fellowships.
- **Promotion of Undergraduate Research:** In 2001, I established the first and only NSF-funded REU (research experience for undergraduates) site at PSU. The objective of this program is to provide opportunities for undergraduate students - with an emphasis on underrepresented minorities and females - to be involved in research projects with the faculty at PSU. The last five years have proven that this special program not only allows students to quickly engage in actual research work in a multidisciplinary environment, but also trains them in using microscopy and microanalysis techniques. The effort has motivated students to pursue advanced degrees and research careers in science and engineering areas. Through this program, I have trained and advised more than 70 undergraduate students and involved them in cutting-edge nanoscience research. Detailed information on this program can be found at [www.reu.pdx.edu](http://www.reu.pdx.edu).

### Other Teaching, Mentoring and Curricular Achievements

- **Curriculum Development:** Over the past six years, I have made significant contributions to both curriculum development and quality teaching with five courses (Ph101, Ph102, Ph381, Ph451/551, and Ph452/552). In particular, the Ph451/551 (Transmission Electron Microscopy of Nanomaterials) and Ph452/552 (Scanning Electron Microscopy and Spectroscopy) curricula—developed in my areas of expertise—has enriched the existing curricula and received strong responses from students. This is reflected by the fact that my courses are filled beyond the enrollment limit each year. In addition to regular teaching, I have offered other advanced courses to the graduate and undergraduate students in my research group each quarter. These courses include: Introduction to Microelectronic Fabrication (Ph405/505), Introduction to Semiconductor Materials; (Ph501/Ph401) and Synthesis and Characterization of Carbon-Based Nanomaterials (Ph401/Ph501). Each course was taught by arrangement. Students were evaluated through a weekly conference and term papers. Each summer for the past five years, I have offered a short training course (one week) on the introduction and application of scanning electron microscopy. The audience consists of the undergraduate students who were recruited to participate in my NSF funded REU (research experience for undergraduates) Program. I have also been invited to give guest lectures in different classes at PSU. For instance, I have given guest lectures for Ph312 (Modern Physics) and Ch510 (Polymer Chemistry) in the Physics and Chemistry Departments, respectively. I was also invited to give seminar lectures at Oregon State University, Western Washington University, Washington State University in Vancouver, and Linfield College.
- **Instruction with Active Student Involvement:** My teaching philosophy is to engage students as active learners rather than passive recipients. I have designed all my classes to have components, such as literature search and individual projects, requiring students' active involvement. Also, in order to effectively teach my courses, I try to know each student as much as possible. For instance, in the first week of class, I always encourage students to meet with me individually. In particular, by having an appointment with each student, I am able to know them personally and discern their special needs for the class. By doing so, I become familiar with students' backgrounds and can arrange my lecture-topics accordingly. My dedication to teaching was recognized when students in the Physics Department selected me as the recipient of the John Eliot Allen Outstanding Teaching Awards, College of Liberal Arts and Sciences, Portland State University, on June 4, 2004.
- **Mentoring High School Students:** Besides training college students, I have been actively involved in promoting science and engineering education to K-12 students. I served as a judge for the 2002 and 2003 Intel Northwest Science Expo, aimed at promoting middle school and high school students' early involvement in science and engineering. Since 2002, I have served as a mentor for the Saturday Academy's ASE (Apprenticeship in Science and Engineering) program and hosted and supervised four high school students doing research in my laboratory. In addition to those regular activities, I have also provided guidance for those high school students who were curious about nanoscience and nanotechnology. In the last six years, I have hosted more than 60 high school students on visits to my research laboratory. I have advised four other students' science projects. Upon finishing their research projects, these students were recruited by Harvard University, Cornell University, Whitman College and Oregon State University. The successful effort earned me recognition as the Outstanding Mentor of 2003–2004 by Siemens Westinghouse Competition of Math, Science, and Technology.



### **Other Community Outreach Achievements**

- **Establishment of a Network for Research and Education:** In the past six years, I have established a network with international, national and regional research institutions and local industry. I have developed collaborative relationships with the Chinese Academy of Science (CAS) in Beijing, China; the National Center for Electron Microscopy (NCEM) in the Lawrence Berkeley National Laboratory; Pacific Northwest National Laboratory; Washington State University; Oregon State University; Intel Corporation; FEI Company; Sharp Laboratories of America, and LSI Logic, to mention just a few. My students are benefiting from this networking, since they are allowed to visit the sites, use their research facilities, and obtain internships. Currently, I am also an honorary professor at both the Research Center for Nanostructured Materials in Qingdao Institute of Chemical Technology and Liaocheng University, in China.
- **Contributions to the University's Capital Campaign:** In helping the University's capital campaign and fund raising, I was consistently invited by the President's Office of the University and the Dean's Office of the College of Liberal Arts and Sciences to present my research to potential donors and to guide tours of my research laboratory and electron microscopy facility. I also served as one of the major speakers for the University's Umbrella Tour of the Capital Campaign activities in 2002, 2003, and 2005. In the last six years, I have participated in more than a dozen such activities.
- **Promotion for Nanoscience and Nanotechnology Research:** On May 1, 2003, I was invited by Senator John McCain, Chairman of the United States Senators Committee on Commerce, Science, and Transportation, to testify in front of the full Committee in Washington, D.C. on the legislation - S. 189: "The 21<sup>st</sup> Century Nanotechnology Research and Development Act." Senator Allen presided over the hearing, while Senator Ron Wyden was the sponsor for this Act and Senators Allen, Lieberman, Warner, Mikulski, Hollings, Landrieu, Clinton, Levin and Bayh were the co-sponsors. This bill was signed by President Bush in 2004. My written testimony is included in the United States Senators' record and can be viewed at [http://www.senate.gov/~commerce/hearings/testimony.cfm?id=745&wit\\_id=2013](http://www.senate.gov/~commerce/hearings/testimony.cfm?id=745&wit_id=2013)

### **Professionally Related Service**

- Served as vice chair for the board of the Pacific Northwest Chapter of the American Vacuum Society (PNCAVS) from 2004 to Present. Has been a board member of the PNCAVS since 2002.
- Serving as a referee for the Journal of Applied Physics, Applied Physics Letters, Advanced Materials, Journal of Materials Research, Chemical Physics Letters, Applied Physics A, Journal of Nanoscience and Nanotechnology, and Nano Letters (2001-Present).
- Serving as a panelist for the National Science Foundation and frequently review proposals from the National Science Foundation, Petroleum Research Foundation of American Chemical Society, and Research Corporation (2001-Present).
- Serving as a thesis committee member for graduate students Todd Dixon (PhD, Physics), Steven Albert (MS, Physics), Luis Almaraz (PhD, Physics), Liwei Ning (MS, ECE) Zifeng Li (MS, Mechanical Engineering), and Ryan Carns (Chemistry), (2000-present).
- Serving as a guest editor for Chinese Science Bulletin of Science in China Press (2003-present).

- Served as a panelist (Invited) to give a testimony before the U.S. Senate Committee on Commerce, Science, and Technology on S. 189 - The 21st Century Nanotechnology Research and Development Act, May 1, 2003.
- Invited by the PSU President to serve as a search committee member for a new Vice President in Finance and Administration, July 2004 – July 2005.
- Served as a member of the Faculty Development Committee in PSU. Responsibilities included reviewing proposals and making decisions for the University's internal research funding programs and professional travel programs (2000-2003).
- Serving as a member of the space committee in the Physics Department (2004-Present).
- Serving as a member of the curriculum committee in the Physics Department (2004-Present).
- Served as a key member for the Graduate Committee in the Physics Department. In charge of graduate admissions and graduate comprehensive exam II (2000-2004).
- Served as a member of the promotion and tenure committee in the Physics Department (2004).
- Served as a lead judge representing the Vacuum Technology Division of the American Vacuum Society for the Intel International Science Engineering Fair in Portland, OR, May 9-15, 2004.
- Invited to serve in the search committee of the Mechanical Engineering Department for recruiting a senior faculty member in the Mechanical Engineering Department (2003).
- Served as a member of the search committee for recruiting a Gertrude F. Rempfer Chair Professor for the Physics Department (2001-2002).
- Served as a search committee chair for recruiting the Electron Microscopy Facility Manager (2003).
- Invited to participate in the Chemistry Department's interview process for a new tenure track faculty member (January 31, 2000).

#### **Memberships in Professional Societies**

- Member of Materials Research Society, 1993 – Present.
- Member of Microscopy Society of America, 1992 – Present.
- Member of the American Vacuum Society, 1999 – Present.
- Vice Chair for the Board of the Pacific Northwest Chapter of the American Vacuum Society, Present.
- Member of the National Honor Society of Phi Kappa Phi, 2004 – Present.

3.

4.

Thank  
you



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in

characterized 8.18 sample. Pretty much the same results as 8.15 sample. Some growth on tip of towers, which varied from towers to towers. Some of them had a long "worm" of aligned tubes which were intertwined with the perimeter tubes, so the worm was pulled off to a side. Others had small growth of what looks like a bundle that never really got started. Other tubes looked like just minimal spaghetti growth of individual tubes, and then some towers had no growth. The bundle tube diameters are ~50-100  $\mu\text{m}$ , but this is a very rough estimate which will require closer characterization. So this method of preparation appears to work to isolate growth in a pattern. We have no tubes bridging the gaps however.

Prepared two patterned samples w/ Pt deposition. One was a p-Si substrate w/ Co sputter coated after Pt tower deposition.

1. Created pattern of  $2 \times 2$  squares about  $\sim 2$  their width apart.
2. Deposited using dep  $2 \times 2$  b. pat. at  $\sim 5000$  magn. w/ a 250 pA current. Collected Pt. rate and we deposited in parallel (not series).  
- built two patterns. 1 was set for a  $2 \times 2$   $1 \mu\text{m}$ , the other,  $2 \mu\text{m}$ .
3. Sputter coated w/ Co target for 90 sec at 32 mA current.

14

The second PoSi pattern was w/o the catalyst.

1. Prepared  $2 \times 2$  patterns of dep  $2 \times 2$  b. pat set  
w/z =  $5 \mu\text{m}$ , all the same as the Co pattern,  
but at  $\times 7000$  mag and a 500 pA current.

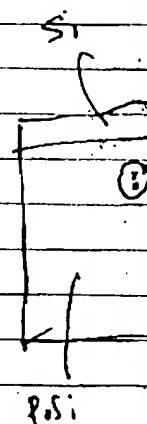
Prepared  $2 \times 2$  patterns of dep  $2 \times 2$  b. pat set  
w/z =  $1 \mu\text{m}$  at  $\times 5000$  mag and 500 pA beam  
current.

2. Spin coated catalyst on

- a. 40  $\mu\text{l}$  - let sit for 30 sec
- b. Spin at 5000 RPM for 15 sec
- c. Spin at 5000 RPM of 15 sec while  
delivering 40  $\mu\text{l}$  catalyst
- d. Bake for 15 min @  $80^\circ\text{C}$

3. Put back in FIB and EE w/ EE small. intr  
using a 500 pA current, pas. Used postdep. pat  
for as long as it appeared catalyst was still  
there. For the smaller  $5 \mu\text{m}$  towers, it was very  
difficult to remove the catalyst. I don't think  
that I removed it all. My catalyst delivery  
procedure may have made it thick or a film.  
The larger pattern of  $1 \mu\text{m}$  towers was possibly  
more successful. The idea was to put a Pt layer  
on then etch PoSi towers w/ a 7d tip.  
Upon inspection initially of the Pt towers, I am  
very suspect as to whether any catalyst stuck  
on them or not.

4. Put in reaction chamber - cross reference to  
reaction chamber log to find parameters -



2:10

1:50 - 3:40

700°C 385 sccm  $H_2$  15 min 100 mbar800°C " + 25 sccm  $C_2H_2$  " "

1) POWDERED CATALYST

2) Seams S:

3) Hipco

-CLM

2:55 - 4:10

700°C 385 sccm  $H_2$  15 min 100 mbar800°C " + 25 sccm  $C_2H_2$  5 min "

1) Seams P-S; PATTERNED LC

2) " " COBALT

3) TUNGSTEN  $\Delta$  LC

4) " " LC

-CLM

★ POSSIBLE LEAK IN SYSTEM. THIS MORNING, PRESSURE WAS 200 mbar (INSTEAD OF ZERO). R

3:30 - 4:40

700°C 385 sccm  $H_2$  15 min } 100 mbar700°C 385 sccm  $H_2$  ? 5 min }25 sccm  $C_2H_2$  }

1) Seams P-S, patterned - LC

Seam

3:30 -

- 700°C 385 sccm  $H_2$  15 min } 100 mbar- 700°C 385 sccm  $H_2$  15 min } 100 mbar25 sccm  $C_2H_2$  5 min }- 700 385 sccm  $H_2$  15 min 100 mbar- 700 385 sccm  $H_2$  ? 5 min bottom w-bp.25 sccm  $C_2H_2$  }

two Pt - Patterned sample

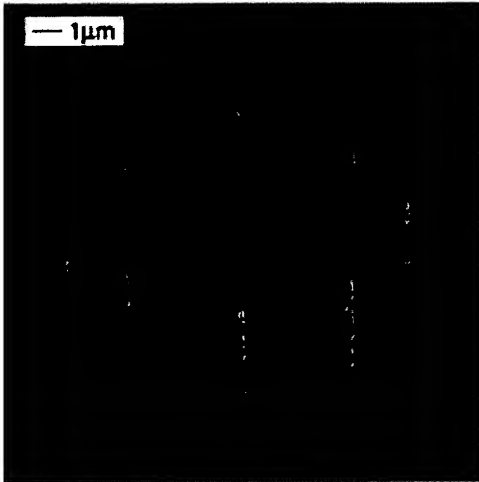
C1 - split charging, 2 - Cobalt loading

EXHIBIT

tabbles

C

## Platinum Deposition



Small Diameter Tower Pt Deposition:

Dwell: 2.0μs

Overlap: 99%

Magnification of deposition: x20,000

Deposition pattern: Filled Box

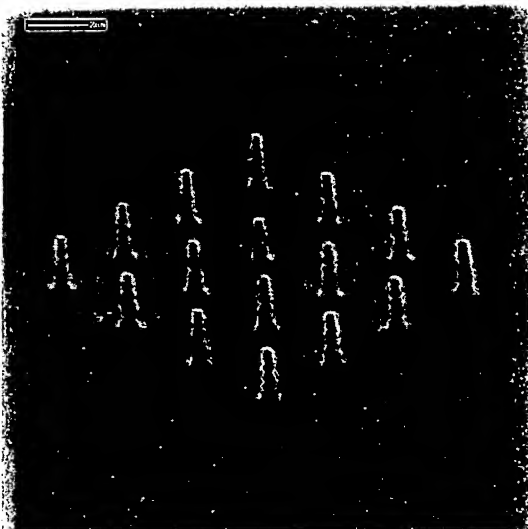
Filled Box size: 0.03μm x 0.03μm

Z axis: 175μm

Time per tower: 5 minutes in series

*The important step in this is constantly adjusting the x and y positions with the x/y adjust knobs to account for drift.*

*Drift can be found by taking fast scanning rate single photo grabs during deposition.*



Small Diameter Tower Pt Deposition:

Current: 2pA (lens 1 voltage 1.000kV)

Dwell: 5.0μs

Overlap: 50%

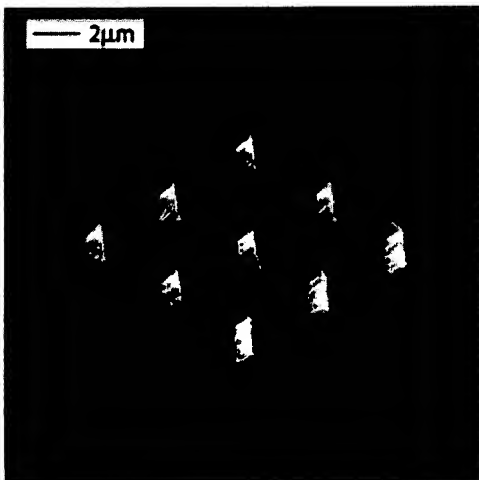
Magnification of deposition: x50,000

Deposition pattern: Filled Box

Filled Box size: 0.15μm x 0.15μm

Z axis: 175μm

Time per tower: 2 minutes in series



Square Tower Pt Deposition:

Current: 6pA

Dwell: 0.4μs

Overlap: 50%

Magnification of deposition: x10000

Deposition pattern: Filled Box centered in screen.

Filled Box size: 1.0μm x 1.0μm

Z axis: 175μm

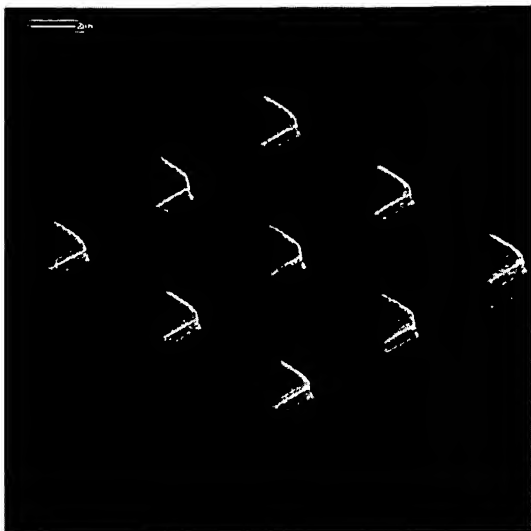
Time per tower: 5:30 minutes, 180° rotation, 3:30 minutes, 180° rotation, 1:30 minutes. All towers were done in series.

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EXHIBIT

tabbles

D



Large Square Tower Pt Deposition:  
 Current: 41pA  
 Dwell: 2.0 $\mu$ s  
 Overlap: -99%  
 Magnification of deposition: x5000  
 Deposition pattern: Filled Box  
 Filled Box size: 2.0 $\mu$ m x 2.0 $\mu$ m  
 Z axis: 175 $\mu$ m  
 Time per tower: 20 minutes, 180° rotation, 15 minutes, 180° rotation, 5 minutes. The towers were deposited in parallel as opposed to the more frequently used series.

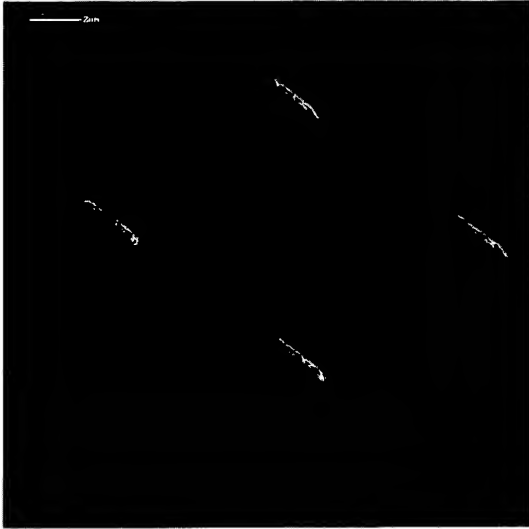


Small Diameter Tower Pt Deposition:  
 Current: 2pA  
 Dwell: 2.0 $\mu$ s  
 Overlap: 50%  
 Magnification of deposition: x15,000  
 Deposition pattern: Filled Box  
 Filled Box size: 0.10 $\mu$ m x 0.10 $\mu$ m  
 Z axis: 175 $\mu$ m  
 Time per tower: 1:30 minutes in series

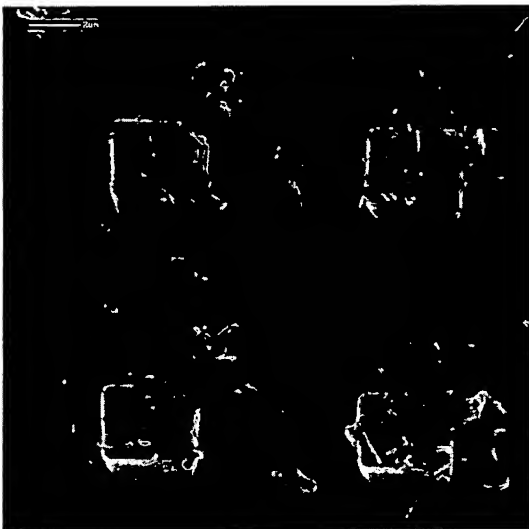
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## Cobalt Sputter Coat



Large Square Pt Deposition:  
Current: 250pA  
Dwell: pt.mtr default  
Overlap: pt.mtr default  
Magnification of deposition: x5000  
Deposition pattern: Created deposition  
pattern of 4, 2.0μm x2.0μm filled boxes  
Filled Box size: 2.0μm x2.0μm  
Z axis: 50μm  
Time per tower: This was dictated by  
setting the z height at 1μm. The pattern  
was deposited in parallel.



Sputter coated with cobalt target for 90  
seconds at 32mA current. Check reactor  
log for growth parameters.

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## Spin Coated Liquid Catalyst



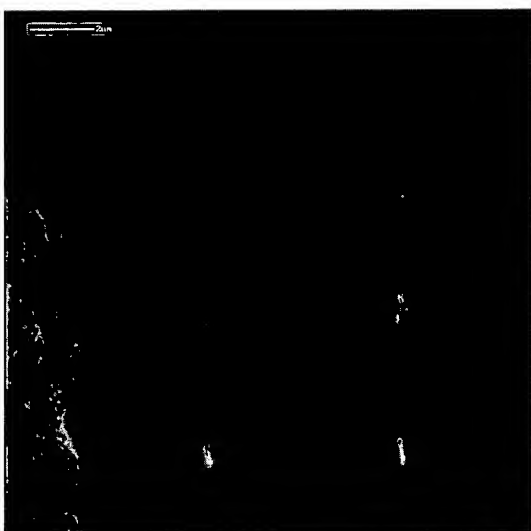
Liquid catalyst was spin coated As follows:

- 25 $\mu$ l carefully delivered to surface of porous silicon substrate such that it remained due to surface tension
- Let sit for 30 seconds
- Spun for 5 seconds at 5000rpm
- Delivered 25 $\mu$ l more while spinning for 5 more seconds at 5000rpm.
- Baked in furnace for 15 minutes at 75°C.

Enhanced Etched pattern of 2x2 squares 9 times to produce the array of towers. This was performed under the following conditions:

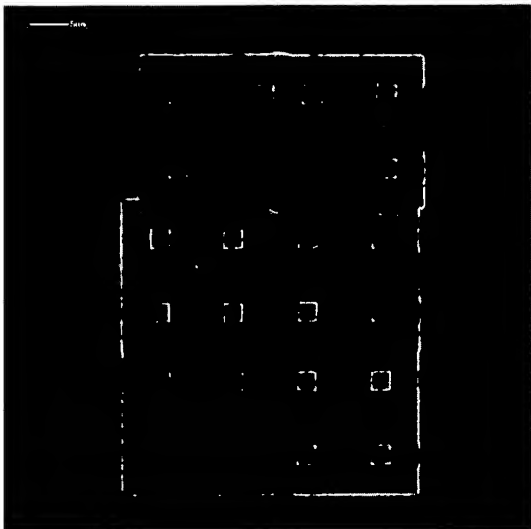
- Current: 500pA
- Dwell: default ee\_small.mtr
- Overlap: default ee\_small.mtr
- Magnification of deposition x7,000
- Time per tower: 7 minutes per 2x2array, each of the nine in parallel.

Check reactor log for growth parameters.

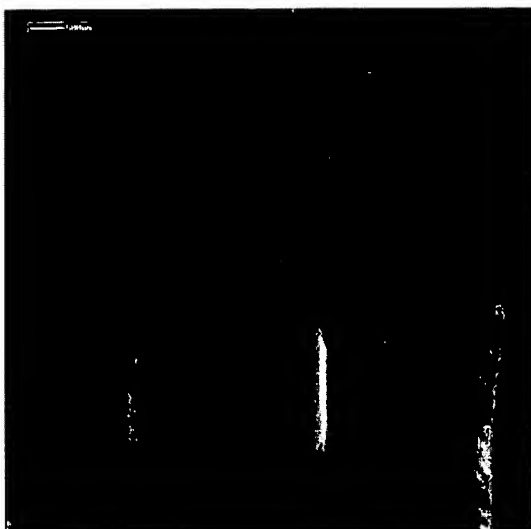
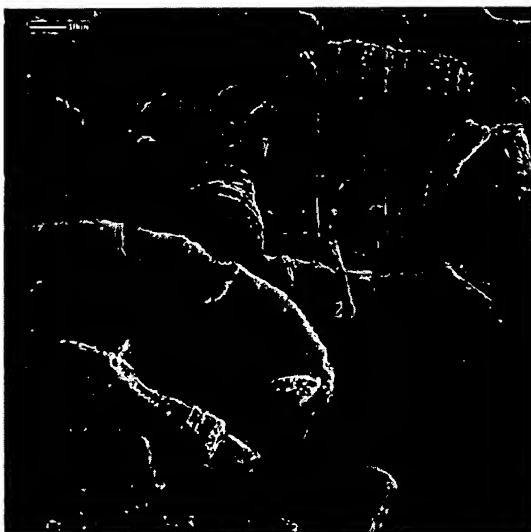


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## Spin Coated Liquid Catalyst



Performed exactly as \_\_\_\_\_ experiment,  
but only etched 6 instead of nine  
patterns.



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## Spin Coated Liquid Catalyst

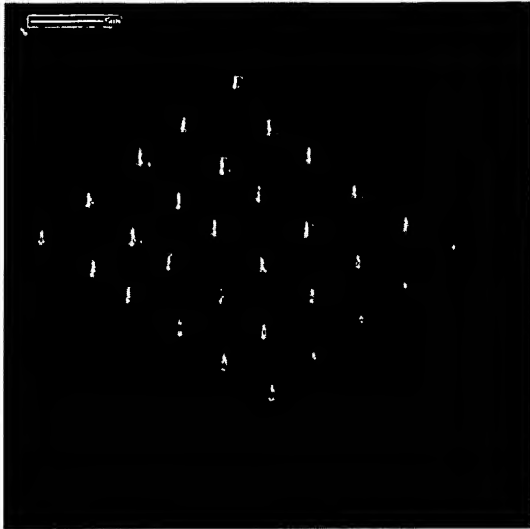


Again, this experiment was performed the same as \_\_\_\_\_. There was a change in the spin coating as follows:

- 40μl carefully delivered to surface of porous silicon substrate such that it remained due to surface tension
- Let sit for 30 seconds
- Spun for 5 seconds at 5000rpm
- Delivered 40μl more while spinning for 5 more seconds at 5000rpm.
- Baked in furnace for 15 minutes at 85°C.



### Cobalt Sputter Coat

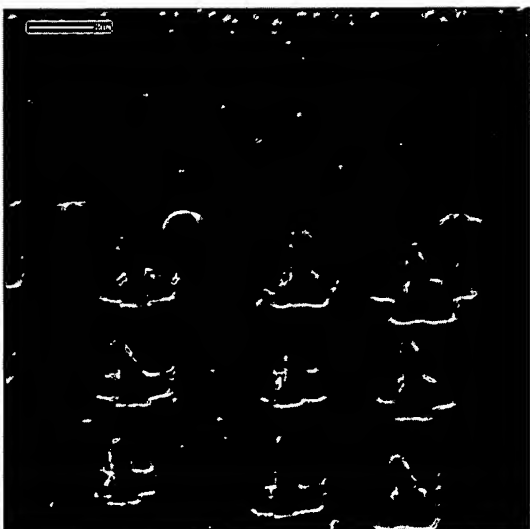
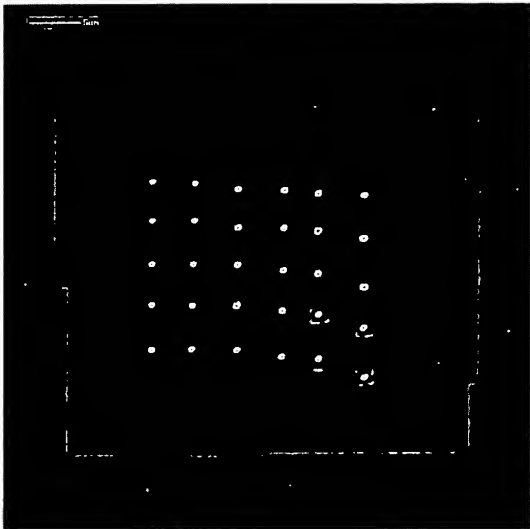


Small Diameter Tower Pt Deposition:  
Current: 2pA (lens 1 voltage 0.36kV)  
Dwell: 2.0 $\mu$ s  
Overlap: 99%  
Magnification of deposition: x15,000  
Deposition pattern: Filled Box  
Filled Box size: 0.10 $\mu$ m x 0.10 $\mu$ m  
Z axis: 175 $\mu$ m  
Time per tower: 2 minutes in series

Cobalt sputter coating was performed with a 30mA current for 120sec.

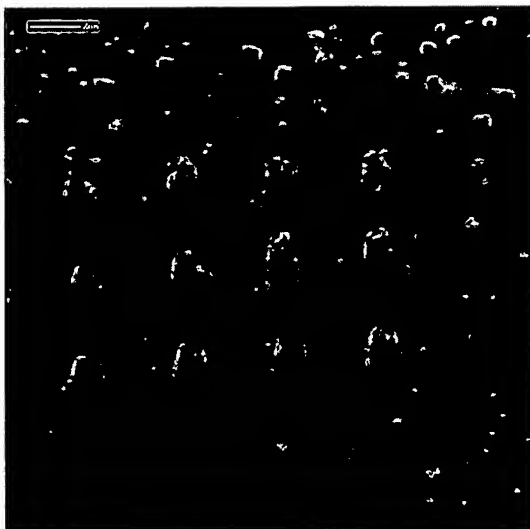
Cobalt removal done with 125pA current and all settings were default of si.mtr. I just drew a box with the milling tool on the FIB and removed the cobalt between the towers a row at a time.

Check reactor log for growth parameters.



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## Cobalt Sputter Coat



Medium Square Tower Pt Deposition:  
Current: 5pA (lens 1 voltage 0.36kV)  
Dwell: 5.0μs  
Overlap: 99%  
Magnification of deposition: x15,000  
Deposition pattern: Empty Box  
Empty Box size: 0.5μm x0.5μm  
Z axis: 175μm  
Time per tower: 5 minutes in series  
The holes in the center were made by  
using all of the same parameters as the  
deposition, but a 0.5μm x0.5μm filled  
box was used. Each hole was milled for  
30 seconds.

Check reactor log for growth parameters.

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